SSD94D0336

Milestone 4
Lightweight Durable TPS

Cooperative Agreement NCC2-9003

November 15, 1994

Prepared by:

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All tasks required to meet Fee Billing Milestone 4 of the Cooperative Agreement NCC2-9003, "TA3 - Lighweight Durable Thermal Protection System" have been completed. These include:

Task 2

- Prepared plan for assembly of blanket/MLI package. The plan is provided here as Enclosure 1.

Task 4

- Prepared plan for evaluation of hook and loop (Velcro-type) fasteners. This is provided as Enclosure 2.

Task 5

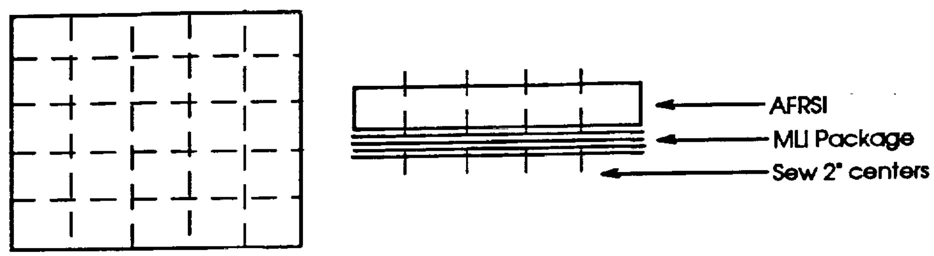
- Prepared document to show logic for relating adverse environments to TPS on vehicle. This document is provided as Enclosure 3.

Preliminary Blanket / MLI Assembly Plan

<u>Proposed attachments:</u>

1. Sew MLI package to blanket insulation (See assembly plan on the next page).
2. Insert MLI package into blanket IML envelope.
3. Attach MLI package to blanket IML with hook and loop.
4. Bond sewn MLI package to blanket IML.

1



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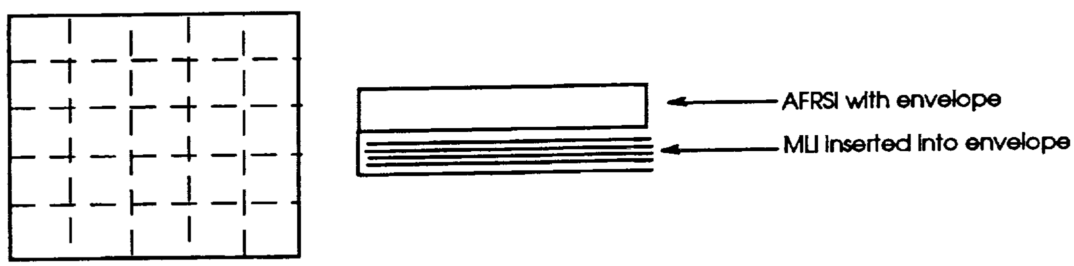

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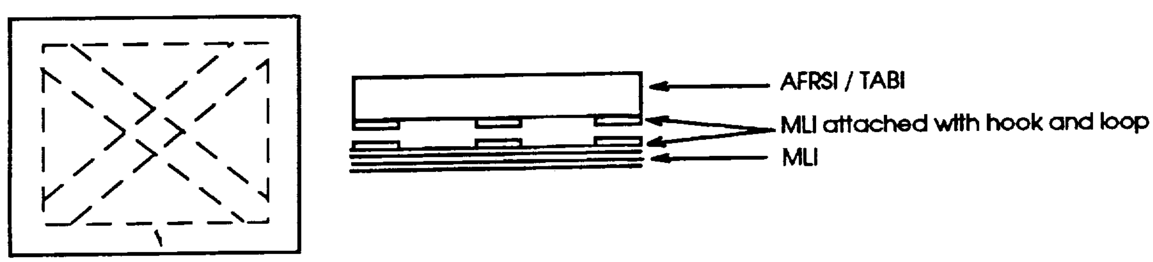

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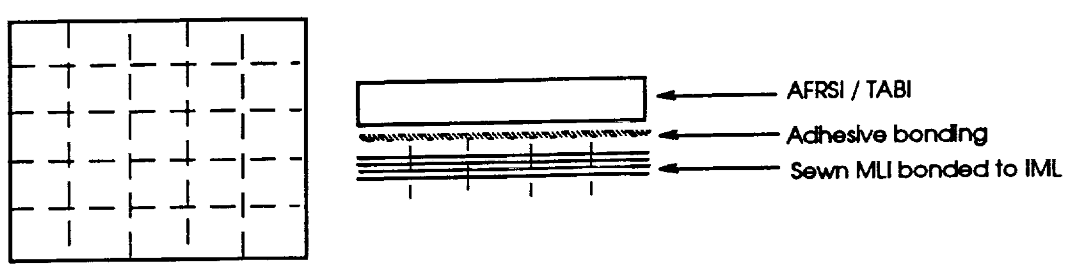


Assembly Plan for Sewing MLI package to blanket insulation (Attachment Method 1)

1. The baseline fabrication procedures for the blanket production unit (PU) shall be per the requirements of Rockwell Specification MA0605-315 except as noted.
2. Calculate the square area of the quilting frame blank and add insulation by weight until the specified density is reached. The additional components are added next, i.e. IML fabric, insulation, OML fabric and perform the first quilt operation on two inch centers. Perform heat cleaning per MA0605-315.
3. Multiple layers of non-metallic reflectives and scrim cloth are then added to the IML side with a final cover of IML cloth (Ref. figure #1 Radiation shield construction). The whole lay-up is then requilted offset half the spacing of the first quilt pattern.
4. When the reflective layers are metallic the procedure is slightly different. The reflective layers and scrim are quilted separately with Teflon coated quartz thread and then quilted to the main body in the same manner and non-metallic assemblies.
5. The completed blankets are heat cleaned at 400°F to remove additional sizing and resins to reduce or eliminate potential outgassing.

4.3 VELCRO ATTACHMENT PROCESS DEVELOPMENT

4.3.1 Introduction/Background

The use of specialty Velcro has been suggested for attaching TPS components to the vehicle structure or foam. Suitable candidates will be evaluated to verify their durability to the SSTO flight and operational environments. Velcro strength/durability will be evaluated on new material and after several removal/replacement cycles. If strength and environmental durability are adequate, methods of attaching the Velcro to the tiles, blankets and various substrates will be explored. A seven tile array will then be fabricated and exposed to humidity, wind/rain, and cold.

4.3.2 Applicable Documents

"An Investigation of the Velcro Hi-Garde Metallic Hook and Loop Fastener System", NASA Ames Research Center, Angela L. Robinson.

4.3.3 Velcro Detailed Requirements

The Velcro supplied from the vendor shall be evaluated by the tests that follow.

4.3.3.1 EVALUATE VELCRO (6h)

This task will characterize and evaluate the various hook and loop materials to verify their durability under SSTO flight and operational environments.

4.3.3.1.1 Detailed Test Article/Test Specimen Description

The specimens will be made from the following materials:

- VELCRO ASTRO II Hook Tape: 1 inch wide, natural color, two selvages, 9 mil PEKKEK (Poly Ether Ketone Ketone Ether Ketone) hook filament.
- VELCRO ASTRO II Loop Tape: 1 inch wide, natural color, two selvages, 252/8 PEKKEK loop yarn.
- APLIX #821 Woven Hook Tape: 1 inch wide, white color, two selvages, woven NOMEX base with 4 mil stainless steel hooks.
- APLIX #820 Woven Loop Tape: 1 inch wide, white color, two selvages, woven NOMEX base with unnapped NOMEX loops.

4.3.3.1.2 Test Procedure

Materials characterization and testing of the hook and loop materials will involve performing the following experiments:

- Material identification/characterization.
  - IR (Infra Red) Spectrometry- to characterize the materials.
  - DSC (Differential Scanning Calorimetry)- to determine melting points.
  - TGA (Thermogravimetric Analysis)- to determine weight loss.
  - VCM (Volatile Condensable Material)- to determine thermal vacuum stability.
- Strength/durability.
  - Tensile strengths of the hook and loop attachment will be measured before and after several removal/replacement cycles. Peel strengths will also be measured.
- Temperature capability.
  - Tensile and peel tests will be conducted at -65°F, 75°F, 200°F, and 350°F in order to measure the hook and loop attachment properties as a function of temperature.
- Environmental resistance.
  - The hook and loop materials will be mechanically tested and evaluated after exposure to the following environmental conditions:
    - Humidity exposure, 95% R.H. 120°F for 120 hours.

Cryogenic exposure, -320°F (liquid nitrogen emersion) and -423°F (liquid hydrogen emersion).

Salt spray exposure, 7 day exposure as described in ASTM B 117

Ease of use.

Techniques of removal and installation of Velcro-backed tiles and blankets will be investigated.

The ability to conform the hook and loop tapes to complex structures will also be evaluated.

4.3.3.1.3 <u>Test Equipment</u>

Characterization of the materials will be done using thermal analysis and spectrographic equipment.
Tensile tests and peel tests will be conducted using Instron test equipment.
Humidity exposures will be conducted in a suitable chamber with controls capable of maintaining ±3°F and ±5% R.H. A chart recorder will be used to document the actual temperature and humidity.
Salt spray exposures will be conducted in a standard salt spray chamber as described in ASTM B 117.
Cryogenic exposure will be accomplished using a test chamber fitted with controlled LN_2 and LH_2 sources.

4.3.3.1.4 <u>Schedule</u>

"Velcro" vendor search initiated	September 1, 1994
Velcro evaluation plan complete	November 15, 1994
Evaluation complete	February 15, 1995

4.3.3.2 VELCRO ATTACHMENT (6i)

This task will involve determining the optimum method for attachment of the hook and loop materials to tile and blanket materials.

4.3.3.2.1 Detailed Test Article/Test Specimen Description

Five 6-x-6-in tile and five 6-x-6-in blanket coupons will be fabricated using different methods of adhesive and mechanical attachment. Specimens will be adhesively bonded to tiles using RTV 560 (MBO130-119 TYII) of bondline thickness from 10 mils to 20 mils and by the use of a structural adhesive HT 424. For blankets, the adhesive bonding process and sewing the Velcro directly to the blanket will be examined.

4.3.3.2.2 Test Procedures

The specimens will be subjected to the temperature conditions of 375°F for 1 hr and -160°F for 1 hr. The specimens will then be subjected to a removal/replacement cycle. Visual inspection will detect any anomalies which will then be documented photographically.

4.3.3.2.3 Test Equipment

All testing will be conducted using Instron mechanical test equipment.

4.3.3.2.4 Sketches and Schematics

4.3.3.2.5 Schedule

Initiate Velcro TPS attachment process	February 15, 1995
Complete blanket and tile attachment	June 30, 1995

4.3.3.3 VELCRO JOINT STRENGTH (6j)

This task will determine the strength of the Tile/Velcro/Structure system before and after several removal/replacement cycles have been conducted.

4.3.3.3.1 Detailed Test Article/Test Specimen Description

Twenty 2-x-2-in, eight 6-x-6-in AETB-12 and two 12-x-12-in blankets attached to a composite substrate by the most promising method evaluated in 4.3.3.1.

4.3.3.3.2 Test Procedure

On all tile specimens, load plates will be applied to the structure and tile surfaces. At room temperature, 1/2" thick 6061 T6 aluminum load plates will be bonded to the structure side and the tile surface using Hysol EA 911 room temperature curing adhesive. Load will be applied using a crosshead rate of 0.05 in/min. Load vs crosshead movement, ultimate failure load, and failure mode will be recorded.

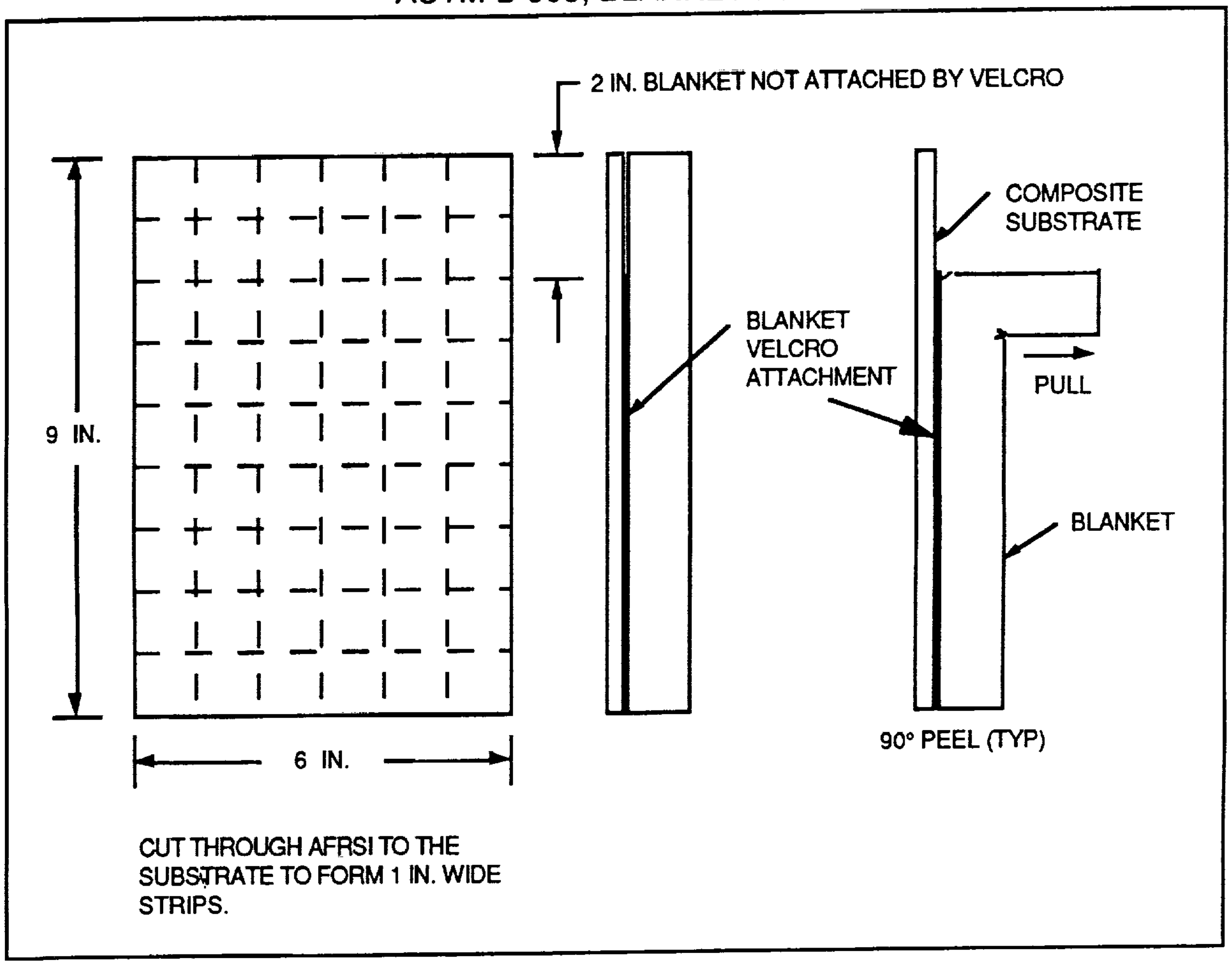
Blanket specimens shall be bonded to the structure and 1" strips shall be cut in from the surface of the blanket through to the structure. The 1" wide blanket strips shall be tested in peel per ASTM D 903.

4.3.3.3.3 Test Equipment

The load tests will be conducted using Instron test equipment.

4.3.3.3.4 Sketches and Schematics

ASTM D 903, BLANKET PEEL



4.3.3.3.5 Schedule

Initiate specimen fabrication	February 15, 1995
Perform joint strength testing	April 30, 1995

4.3.3.4 VELCRO ATTACHMENT AREA (6k)

This task will determine the attachment area required (tile/substrate) for adhering tiles to the structure below. Also examined will be the vibroacoustic resilience and venting properties of a 24-x-24-in blanket attached to the structure using Velcro.

4.3.3.4.1 Detailed Test Article/Test Specimen Description

Five 6-x-6-in AETB-12 tiles bonded using only a 5-x-5-in Velcro footprint and five 6-x-6-in AETB-12 tiles bonded using a 6-x-6-in Velcro footprint (full footprint) for use in flatwise tensile testing.

One 24-x-24-in blanket attached to an aluminum substrate using 24-x-24-in Velcro for use in vibroacoustic and venting tests.

4.3.3.4.2 Test Procedures

On all tile specimens, load plates will be applied to the structure and tile surfaces. At room temperature, 1/2" thick 6061 T6 aluminum load plates will be bonded to the structure side and the tile surface using Hysol EA 911 room temperature curing adhesive. Load will be applied using a crosshead rate of 0.05 in/min. Load vs crosshead movement, ultimate failure load, and failure mode will be recorded.

The blanket specimen will subjected to ascent/descent pressure profiles and examined for disbonds or any other anomalies. The blanket will then be subjected to vibroacoustics and venting as described in procedures listed in Appendix H (DTP 6451-817) and Appendix K (DTP 6451-820).

4.3.3.4.3 Test Equipment

Tensile tests will be conducted using Instron test equipment.
Venting requirements will be achieved in an environmental chamber.
Vibroacoustic loads will be applied using the equipment listed in Appendix H (DTP 6451-817)

4.3.3.4.4 Schedule

Initiate fabrication of test specimens	February 15, 1995
Perform joint strength test	April 30, 1995

4.3.3.5 VELCRO ENVIRONMENTAL EFFECTS (6I)

This task will determine the effects of humidity, wind/rain, salt spray and cryogenic exposure on Velcro attached tiles and blankets. Analysis for GO_2 and GH_2 at the Velcro joint will be conducted to evaluate safety concerns.

4.3.3.5.1 Detailed Test Article/Test Specimen Description

Five 3-x-3-in AETB-12 tile coupons and five 6-x-6-in AFRSI blanket coupons.
One 15-x-40-in seven tile array and one 24-x-24-in blanket array.

4.3.3.5.2 Test Procedure

Expose five tile and three blanket coupons to the following conditions,
Humidity exposure, 80% R.H. 100°F for 120 hours.
Wind/Rain exposure will be conducted as is described in Appendix F (DTP 6451-815).
Salt spray exposure, 7 day exposure as is described in ASTM B 117.
Cryogenic exposure, the coupons will be exposed to -150°F for 1 hour. This cycle will be repeated 10 times.
Flatwise tensile testing shall be conducted on all coupons and unexposed controls at room temperature and 0.05 in/min crosshead rate.

The two arrays (blanket and tile) will be subjected to launch pad conditions. Arrangements will be made with KSC to allow placement of the panels near the launch pad for a 60 day exposure. Visual inspection and photographic documentation will be recorded. Bond verification will be conducted per MLO601-924 "Process Bond Verification of RSI Tiles".

One tile and one blanket will be fitted with a capillary sampling tube embedded in the Velcro. The backface structure temperature will be cooled using LN_2. The Velcro interface will be monitored for any deviation from the normal concentration of GO_2 and GH_2 using multiple gas analyzers.

4.3.3.5.3 Test Equipment

Tensile tests will be conducted using an Instron test machine.
Humidity exposures will be conducted in a suitable chamber with controls capable of maintaining ±3°F and ±5% R.H. A chart recorder will be used to document the actual temperature and humidity.

Wind/Rain exposures will be applied using the equipment listed in Appendix F.
Salt Spray exposure shall be conducted in a standard salt spray chamber as is listed in ASTM B 117.
Cryogenic exposure shall be accomplished using a test chamber fitted with a controlled LN_2 source.

4.3.3.5.4 Schedule

Initiate specimen fabrication	February 15, 1995
Initiate adverse environments testing	August 31, 1995
Adverse data collection complete	September 30, 1995

Internal Letter

Rockwell International

Date: November 9, 1994

No: 284-400-95-152

TO: (Name, Organization, Internal Address)
- Gerald Crofut
- Data Management - SSD
- D/328,841,BB25
X0017

FROM: (Name, Organization, Internal Address, Phone)
- E.T.Watts
- SSD
- D/284,841,DA33
- X3031

Subject: SSTO, TA3 - Task5. Data Transmission: Adverse Environments Definitions

This IL documents transmission of data included herein, describing adverse environments of an SSTO vehicle and a logic for relating these environments to TPS components and locations. This data serves to fulfill milestone #4 of task-5 of cooperative agreement NCC2-9003. The environments are described briefly and supported by data taken from the open literature. Data has been taken from standard, reliable sources, but due to the complex nature there remains some uncertainty in these environments.

The logic for relating the adverse natural environments to TPS components and locations will require the following accomplishments:

1) Community agreement on details of the adverse environments
2) Definition of mission requirements
3) Establishing interaction of adverse environments with specific TPS components

Testing of TPS components under simulated environmental conditions can then be performed with relation to mission requirements. Discussion of the logic for relating adverse environments to TPS components will be a primary topic of the first workshop on adverse environments at NASA-Ames on November 17, 1994.

Eric Watts
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cc:

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B. Syms	DA33
C. Thatcher	DA33

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Definitions of Adverse Environments for Thermal Protection System Materials TA-3, Task-5

Thermal protection system materials for a single stage to orbit (SSTO) vehicle will be required to perform under a range of demanding natural environmental conditions. The TPS materials developed under this TA will be tested under simulated environment conditions to demonstrate their robust character. This document describes the adverse environments expected for an SSTO vehicle but does not the address induced environments such as vibro-acoustics, aerothermal heating, or aerodynamic loads as these conditions will come from detailed vehicle analyses and are not part of the natural environment.

1.0 Ground/Pad Environments

1.1 Salt Air

Vehicles on the launchpad will be subjected to the corrosive effects of salt air. Standard "salt fog" testing, such as ASTM-B-117, should be used to evaluate materials response to the corrosive environment.

1.2 Wind and Rain

Wind driven rain may permeate the TPS materials, adding weight to the vehicle. The yearly averaged maximum wind speed for the KSC area is 46.8 knots[1]. Design maximum rain rates for the same area are shown in Table 1.2.1 below[2]:

Table 1.2.1 Design maximum rainfall rates for KSC[1].

Duration	Rate [in/hour]
1 min	19.4
5 min	8.7
15 min	5.0
1 hr	2.5
6 hr	1.0
12 hr	0.7
24 hr	0.5

Testing for this environment has been standardized by NASA/Rockwell and utilizes conditions in Table 1.2.2, below.

Table 1.2.2 Rockwell standard wind/rain test parameters.

Condition	Orientation	Wind [knots]	Rain [in/hour]	Duration [min]
1	45°	no wind	2.2 - 5.5	63 - 67
2	45°	4.4 - 8.4	5.7 - 11.7	24 - 28
3	90°	35 - 55	10 - 25	9 - 11

Condition 3 is based on the most extreme conditions expected. Conditions 1 and 2 represent less severe weather.

1.3 Frost and Ice
Weather and vehicle conditions may combine to freeze water in or around TPS materials. Different scenarios are possible, Figure 1.3.1. The extreme cold of stored cryogens and/or subsequent freezing temperatures may freeze rain to form ice between blankets and tiles. The low temperatures of the pad environment and stored cryogens, coupled with humidity, may create frost within blankets and tiles. This may happen since water vapor can be transported by diffusion into the interior of blankets and/or tiles.

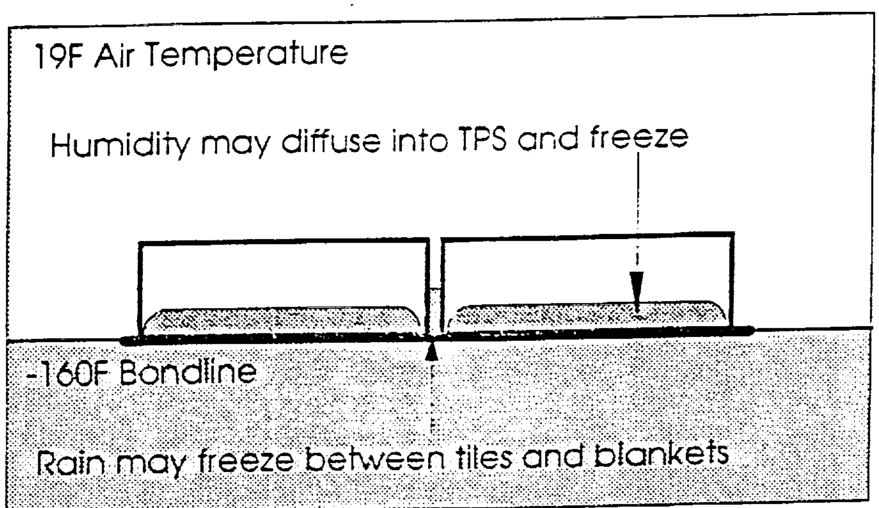

Figure 1.3.1 Rain and humidity may freeze in/between TPS materials.

Conditions on the launchpad that may contribute to ice/frost formation are as follows.

Worst case launchpad temperature conditions[3]:

TPS/Cryo-Insulation bondline temperature:	-160 °F
Extreme cold launchpad temperature expected:	19°F

Liquid water sources:

Precipitation in the form of rain	
Humidity concurrent with cold temperature:	87.9% at 07:00 AM
	62.1% at 13:00 PM

2.0 Ascent/Descent Environments

The primary threat to TPS materials during ascent is impact with hydrometeors. These may be rain drops, cloud droplets, or frozen ice crystals. In order to balance the operational requirement of "launch on demand" with the potential for damage, impact with each of these hydrometeor classes must be considered.

2.1 Rain

The natural rain environment is characterized by the distribution of rain drop size which is a function of the rate of rainfall. This relationship is depicted in Figure 2.1.1, from reference 3.

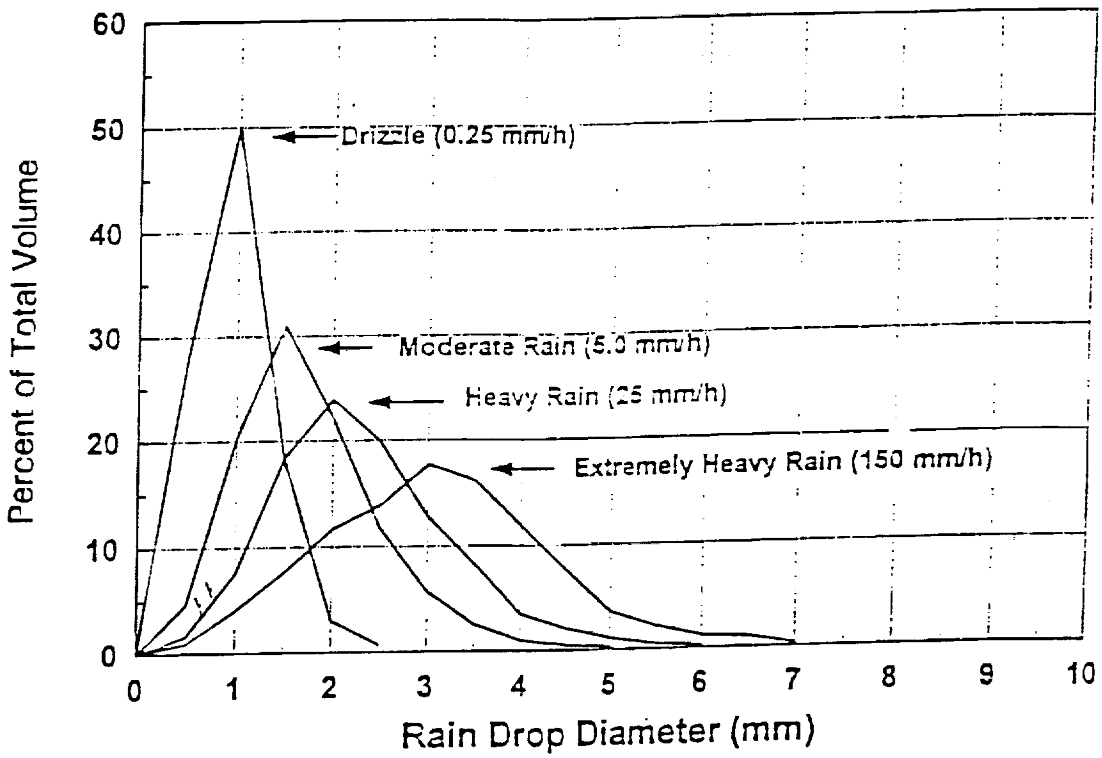

Figure 2.1.1 The size distribution of rain drops is a function of rainfall rate. The "standard" drop size of 2mm is based on a 1 inch per hour rate.

The probability of *not* accumulating various quantities of rain on a given day, at the Kennedy Space Center and Vandenberg Air Force Base, are shown in Table 2.1.1. These data indicate the small percentage of time that significant amounts of rain fall.

Table 2.1.1 Probability of not exceeding given rainfall for any given day[2]

Rain [in]	KSC	Vandenberg
0.0	58.6	70.3
trace	69.9	86.9
0.01	72.5	88.7
0.05	77.9	91.7
0.1	81.4	93.2
0.25	86.9	95.7
0.5	91.8	97.8
1	96.2	99.3
2.5	99.5	99.9
5	99.9	100.0

The intensity of rainfall declines with increasing altitude. This fact is depicted in Table 2.1.2 below (from ref. 3) which shows the percentage of surface rainfall intensity at various heights above the ground.

Table 2.1.2 The rain fall rate decreases as altitude increases.

Altitude (km)	Altitude (feet)	Percent Surface Rate
surface	surface	100
1	3273	90
2	6547	75
3	9821	57
4	13094	34
5	16368	15
6	19642	7
7	22915	2
8	26189	1
9	29462	0.1
>10	>32736	<0.1

General classes of rain also are associated with altitude, and suggestions for simple generalizations have been made. Figure 2.1.2 is one such effort that attempts to stratify rain types (rates) with altitude[8]. Although the natural environments do not neatly divide as shown in the figure, divisions such as these are necessary to facilitate simulation test development.

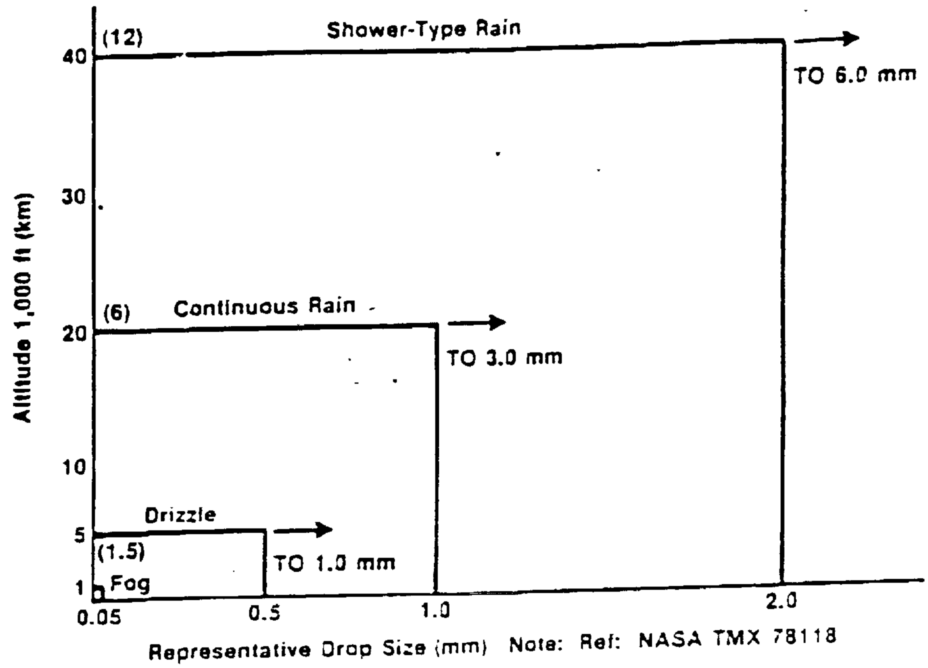

Figure 2.1.2 Simplified definitions of rain types are required for test development.

2.2 Clouds
Flight through clouds will see impact velocities defined by vehicle flight profiles. Drop size distributions however, are much different than typical rain fields. Models, based on measured data[4], have been developed to describe droplet distributions in many different cloud and fog types. These are shown in Figure 2.2.1 and 2.2.2.

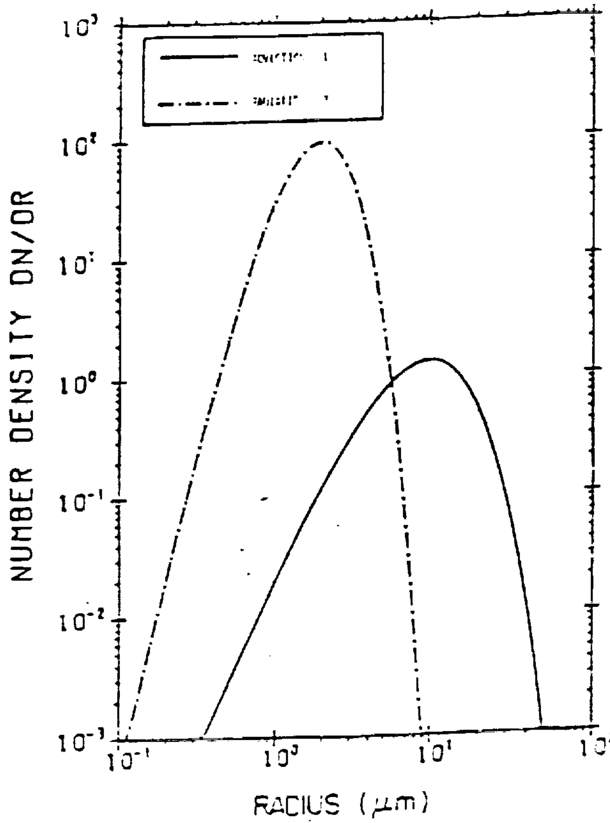

Figure 2.2.1 Drop size distributions for various fog types.

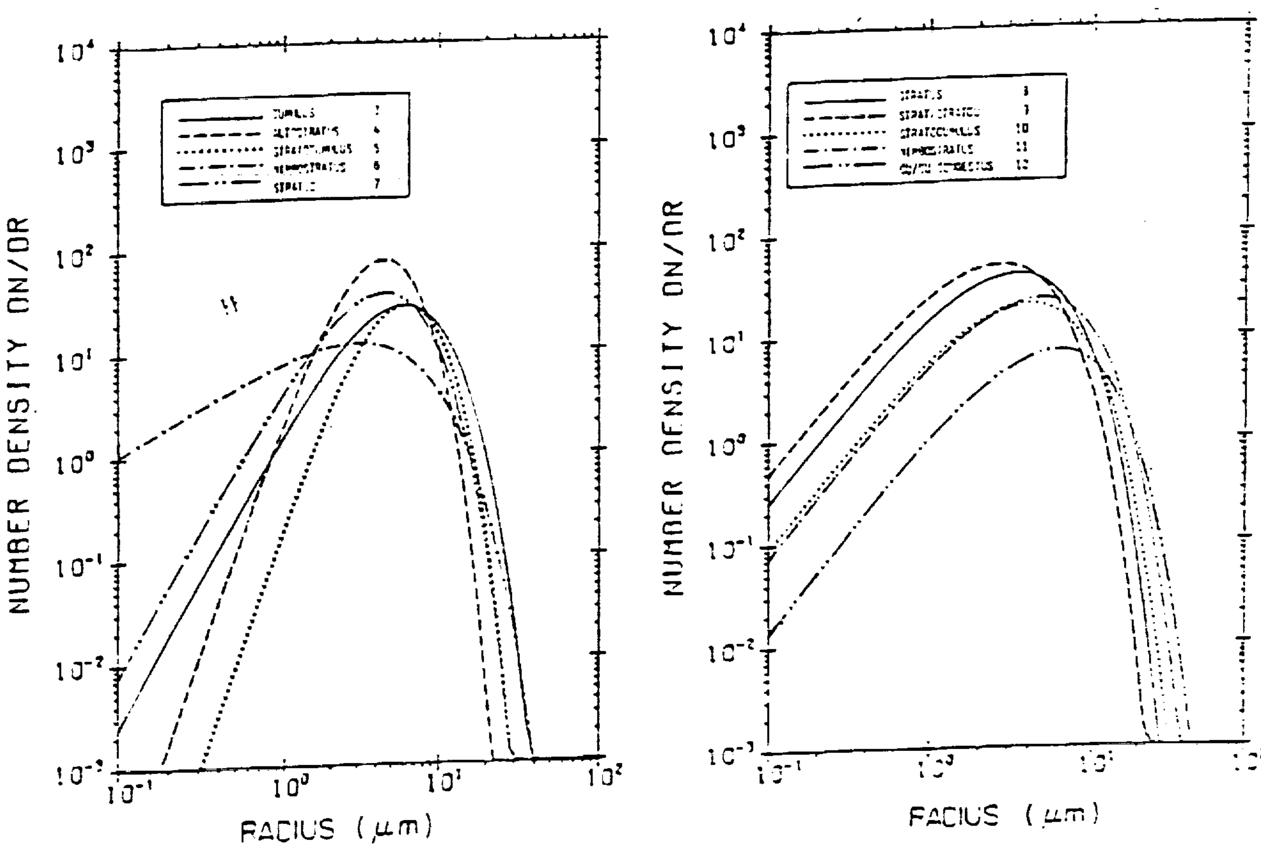

Figure 2.2.2 Drop size distributions for various cloud types.

2.3 Ice Crystals

At altitudes over 7 km water exists only as ice crystals. Below approximately 4.5 km water is liquid and in between there is a combination of the two. Ice crystal measurements are shown in Figure 2.3.1 below, for high cirrus clouds (from reference 4).

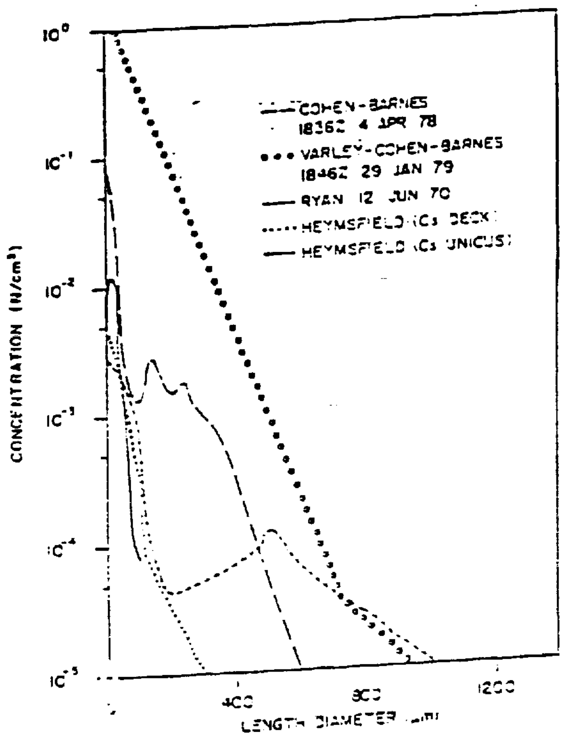

Figure 2.3.1 Ice crystal dimension for high cirrus clouds.

2.4 Hydrometeor/Vehicle Interactions

The interaction of all types of hydrometeors with aerospace vehicles is characterized by impact velocities and impact angles. Sizes and shapes of these impactors are derived from the natural environments defined in sections 2.1 - 2.3. Impact conditions depend critically on the specific vehicle geometry and flight parameters which are not currently available for the SSTO. The following discussion uses Space Shuttle data to illustrate analysis required for a thorough understanding of SSTO/hydrometeor impacts.

The velocity of impact between hydrometeors and an SSTO vehicle will be determined by the vehicle velocity profile on ascent and descent. Such a velocity profile is shown in Figure 2.4.1 for a nominal Space Shuttle mission, similar types of curves will be used for the SSTO.

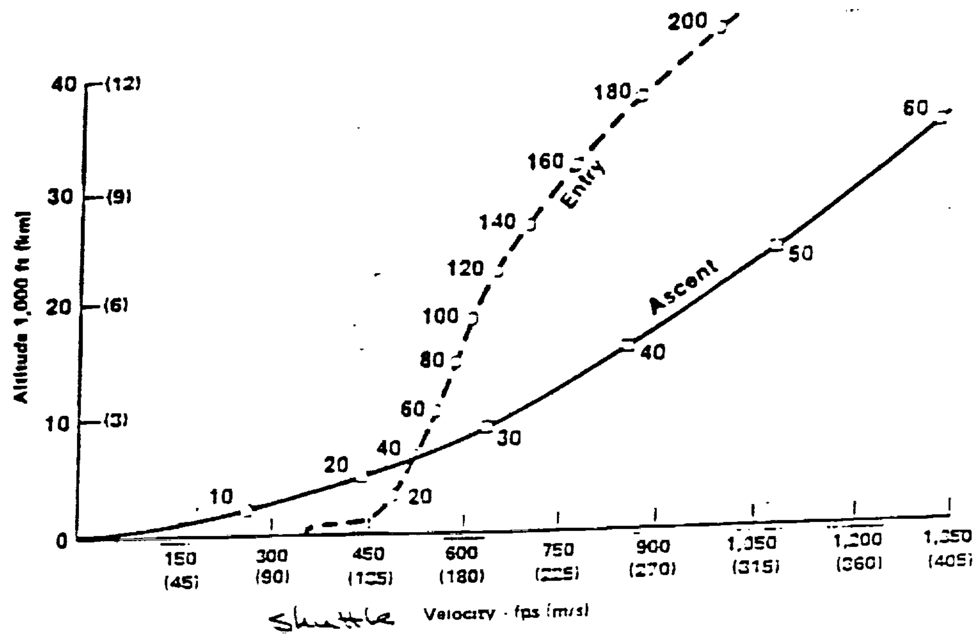

Figure 2.4.1 Velocity profile, shown here for shuttle, determines the rain impact condition.

Establishing test conditions will require integration of vehicle velocities and rain altitude profiles such as those shown in Figure 2.1.2. Previous work on the shuttle program used Figures 2.4.1 and 2.1.2 to derive worst case rain exposure conditions, these are shown in Table 2.4.1[9].

Table 2.4.1 Worst case rain exposure conditions for a nominal Shuttle mission

Max. Conditions		Ascent	Descent
Drizzle	Velocity Duration Altitude	140 m/s 23 sec 1.5 km	160 m/s 32 sec 1.5 km
Continuous	Velocity Duration Altitude	315 m/s 46 sec 6.0 km	190 m/s 110 sec 6.0 km
Shower	Velocity Duration Altitude	510 m/s 66 sec 12.0 km	230 m/s 190 sec 12.0 km

This table begins to address vehicle parameters and rainfall rates, however comprehensive testing will also require evaluation of rain drop size distributions.

The raindrop impact angle with respect to the vehicle surface is critical. This angle is determined by vehicle flight profile. Specifically, the impact conditions can be determined from calculating the interaction of hydrometeors with the vehicle aerodynamic flowfield, Figure 2.4.2[10].

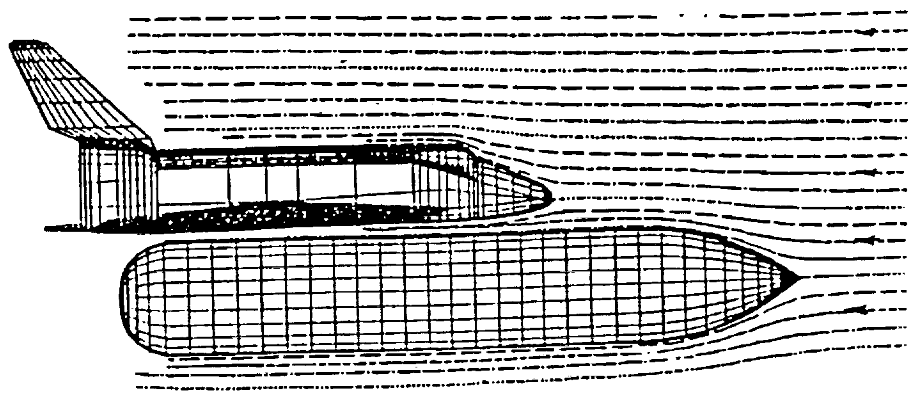

Figure 2.4.2 Hydrometeors must interact with the vehicle aerodynamic flowfield before impact. A Calculated flowfield is shown.

There are two primary issues involved in hydrometeor/flowfield calculations; drop impact angles and drop shape at impact. Hydrometeors are accelerated in the flow field and hence impact at angles different than a static geometric evaluation would predict. Secondly, while being accelerated, liquid drops are also distorted by the flow field so that at impact they are non-spherical (this may be important when attempting to simulate rain exposure in the laboratory). Drops may also break up during acceleration, putting a limit on impacting drop size since larger drops are inherently less stable. This analysis can provide detailed information about drop sizes, shapes, and angles at the time of impact on different vehicle locations. Figure 2.4.3 shows the path of raindrops interacting with the shuttle flowfield on ascent[10].

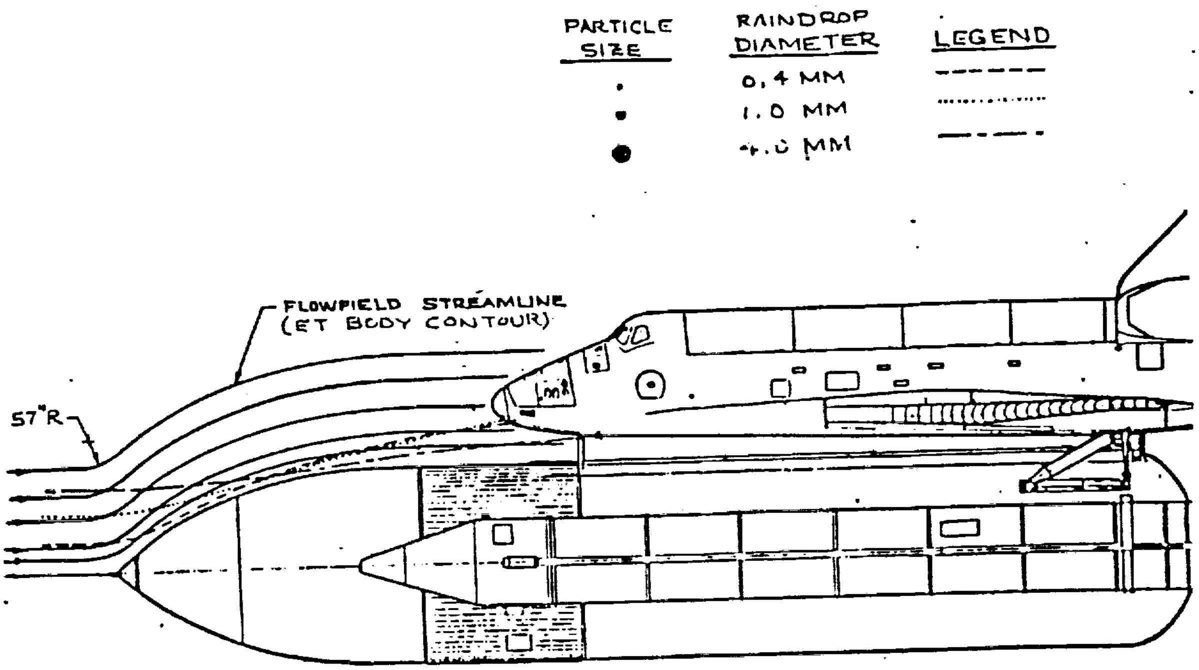

Figure 2.4.3 Calculated raindrop paths are shown interacting with a nominal shuttle subsonic flowfield.

2.5 Lightning
The SSTO vehicle may be subject to lightning strike during ascent and descent. TPS materials must be resistant to lightning effects in order to assure vehicle safety. The potential for lightning strike is proportional to the number of thunderstorm days, as shown in Figure 2.4.1.

Lightning can be positive or negative and can be between clouds (inter/intracloud) or cloud-to-ground strokes. Little data is available for inter/intracloud lightning, but it suggests this type of lightning does not carry the intensely high peak currents of a cloud-to-ground stroke. Considering only cloud-to-ground lightning is a conservative approximation. Positive charge strokes are less frequent, but are of longer duration and higher average current and hence greater total energy. Both positive and negative lightning strokes can be damaging.

When a flying vehicle is included as part of the lightning conduction path, significant current can be transferred over or through the vehicle materials. Once a conducting path is established one or more return strokes carry the huge, potentially damaging currents. Initial stroke attachment typically occurs at the vehicle nose, wing edges, tail, or other extremities. Since the lightning stroke occurs over a finite time interval and the vehicle has a significant velocity, the lightning stroke can travel across the vehicle. This is the swept stroke phenomenon.

Vehicle surfaces are classified as zones for the purposes of lightning testing. Zone-1 are those points on the vehicle surface where initial attachment is likely and Zone-2 is where a swept stroke is likely to pass. Lightning testing is used to simulate the effects in both zones.

The first return stroke of a lightning bolt is the most severe and the range of peak currents are shown in Figure 2.4.2. The shuttle must be able to withstand a lightning stroke with characteristics shown in Figure 2.4.3.

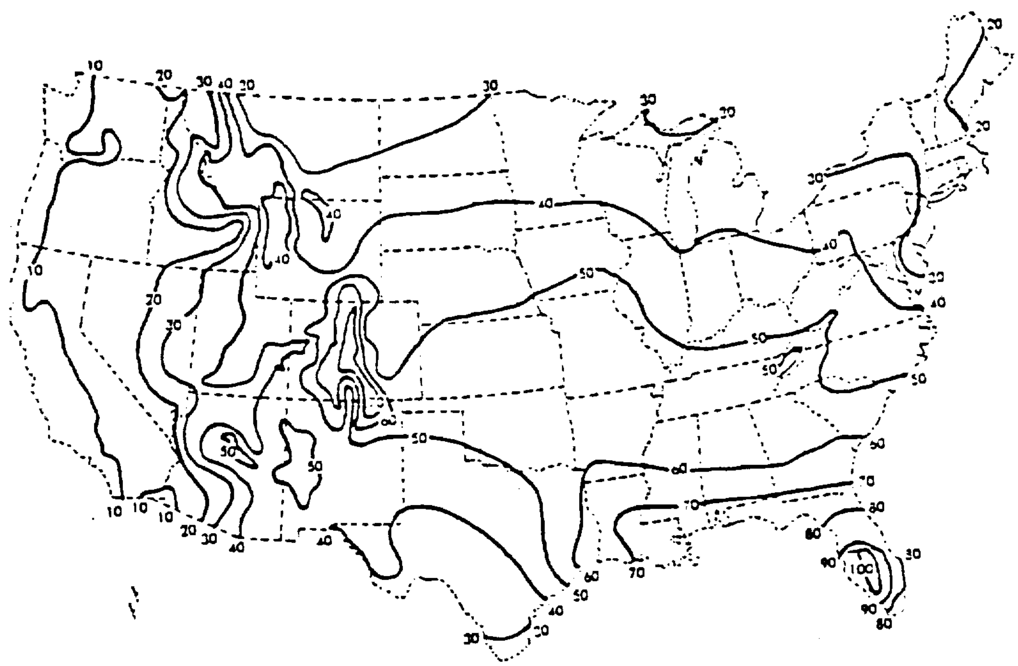

Figure 2.4.1 Number of thunderstorm days per year[7].

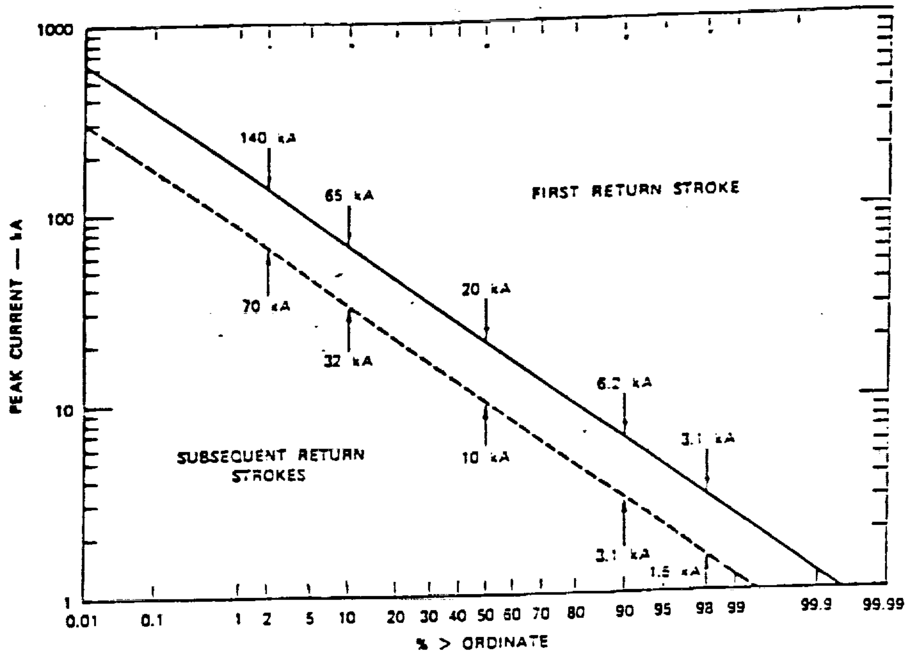

Figure 2.4.2 Probabilities associated with first return strokes of a given peak current(7).

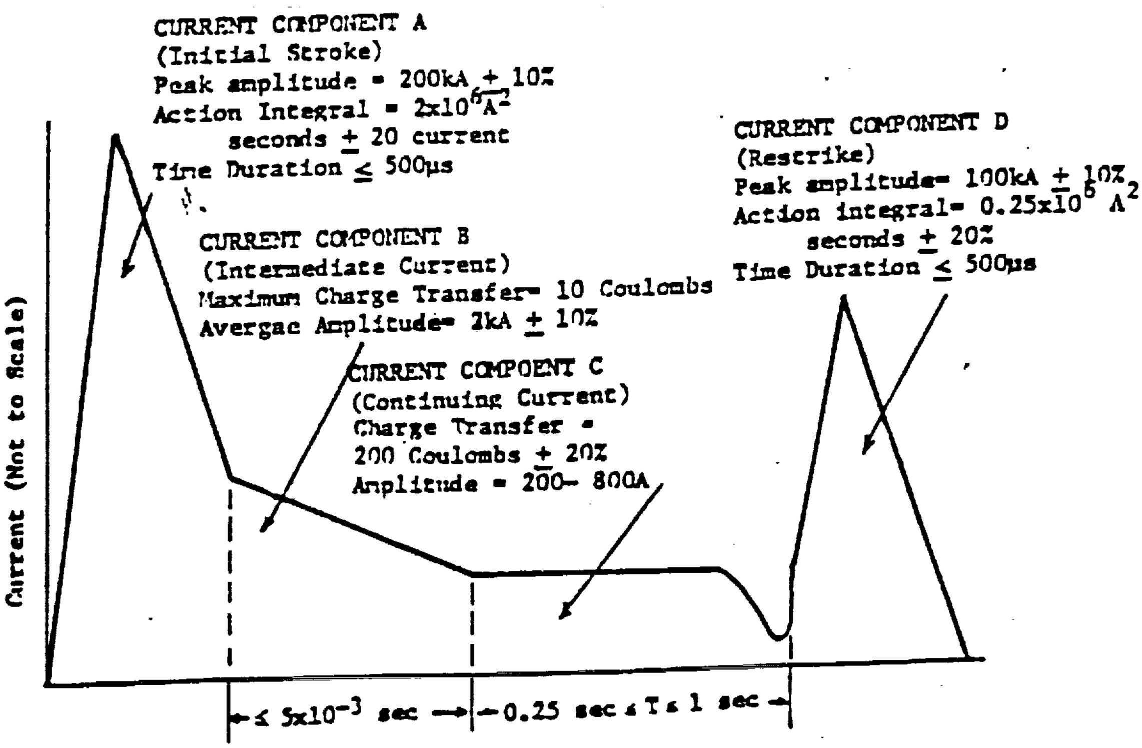

Figure 2.4.3 Lightning stroke characteristics for shuttle testing(6).

3.0 Orbital Environments

The primary threat to a space vehicle on orbit is hypervelocity impact from meteoroids and space debris. Materials exposed to the space environment must also be resistant to the effects of atomic oxygen, solar radiation, high energy particles, vacuum, etc.[11]. Atomic oxygen has been shown to degrade TPS material waterproofing[12] and is explicitly discussed here.

3.1 Meteoroids and Space Debris

Meteoroids and space debris are natural and man made materials respectively, which travel at high velocities relative to orbiting spacecraft and pose a substantial threat of damage. These two environments are described separately. Meteoroids are in orbit around the sun and consequently have extremely high velocities as shown below in Figure 3.1.1. Space debris is in orbit around the earth with impact velocities comparable to spacecraft orbital velocities. The velocity distribution for debris is also shown in Figure 3.1.1.

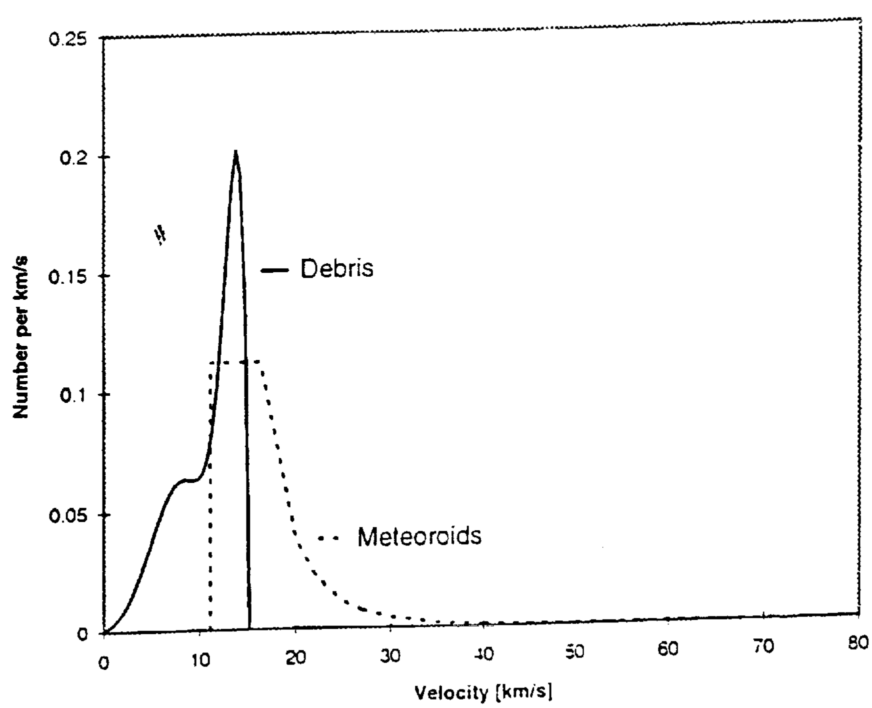

Figure 3.1.1 Velocity distribution for meteoroids and space debris.

The predicted fluxes, based on standard meteoroid and space debris models(5), are shown in Figure 3.1.2. Larger particles, capable of causing critical damage, are predominantly man made debris. However, both meteors and man made debris contribute to the substantial threat from hypervelocity particle impact.

In order to calculate impact risks of the meteor and space debris environment, SSTO vehicle geometry and mission profiles must be defined. For this purpose, a "vehicle" has been defined as a cylinder 176 feet long and 35 feet in diameter. The probability of impact to this SSTO "vehicle" for meteoroids and space debris is shown below in Figure 3.1.3. For the purpose of this calculation a nominal 3 day space station re supply mission has been used. It should be noted that particles capable of causing critical damage to the Space Shuttle (i.e. loss of vehicle), have been estimated in the range of ~10^{-4} to .5 grams(13).

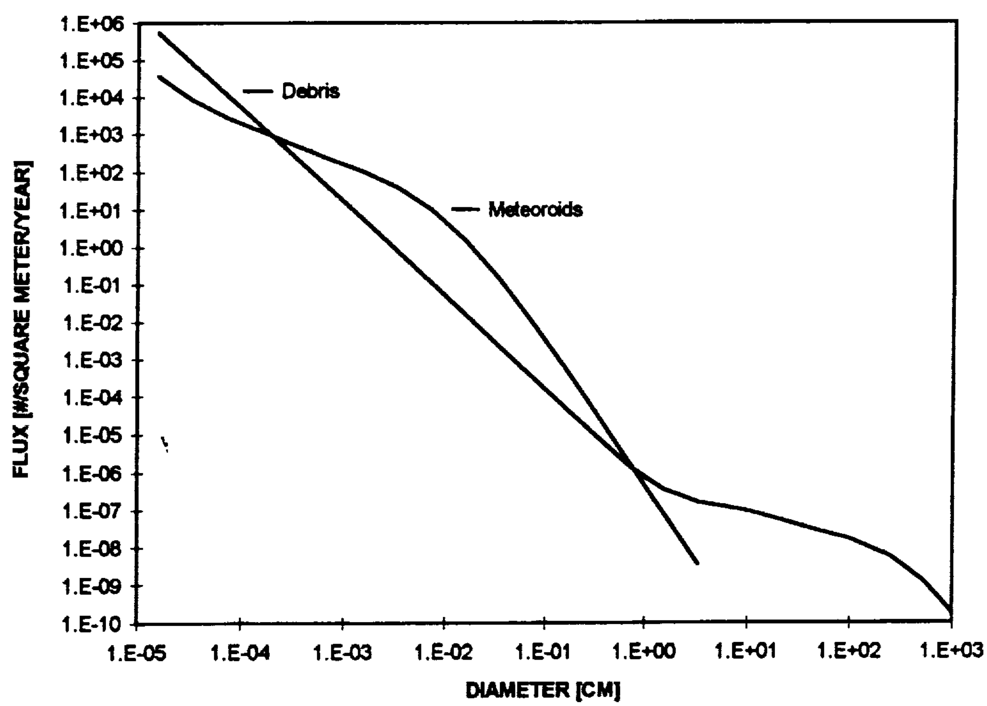

Figure 3.1.2 Expected number of meteoroids and space debris particles is highly dependent on particle size.

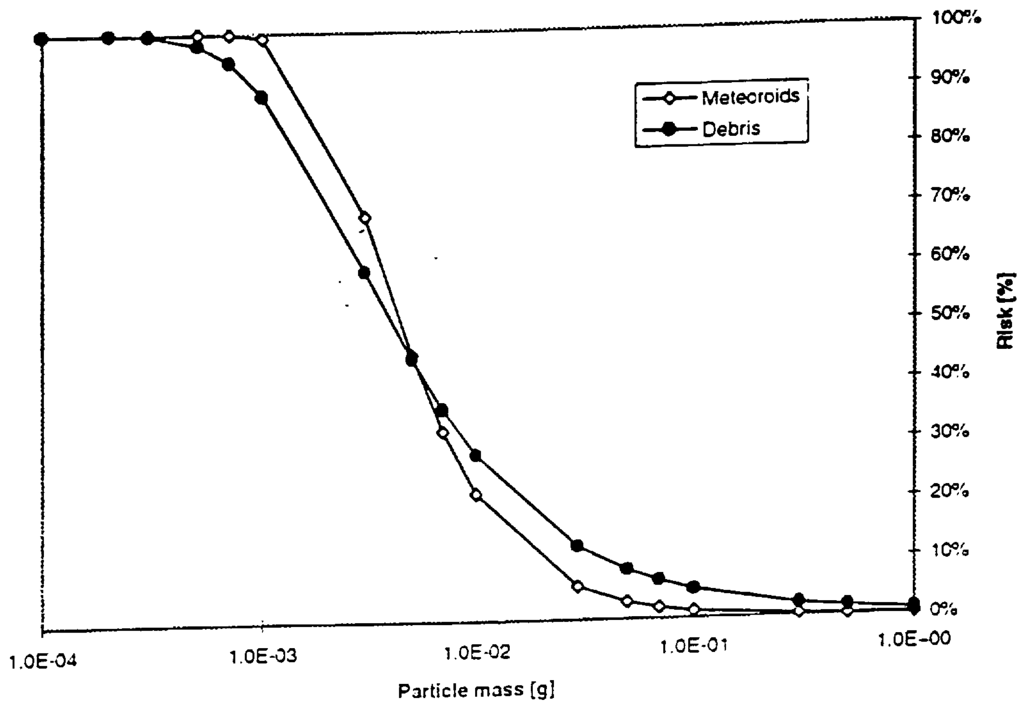

Figure 3.1.3 Probability of meteoroid and space debris impacts for 5 SSTO "vehicles" assuming 100, 3-day missions per vehicle.

3.2 Atomic Oxygen

Materials exposed to the low earth orbit environment must be chemically stable with respect to the effects of atomic oxygen. Atomic oxygen exposure for a typical SSTO space station re supply orbit (altitude=407 km, inclination=51.6°) is shown below in Figure 3.2.1. This calculation is based on the MSIS-86 standard atmosphere model[14].

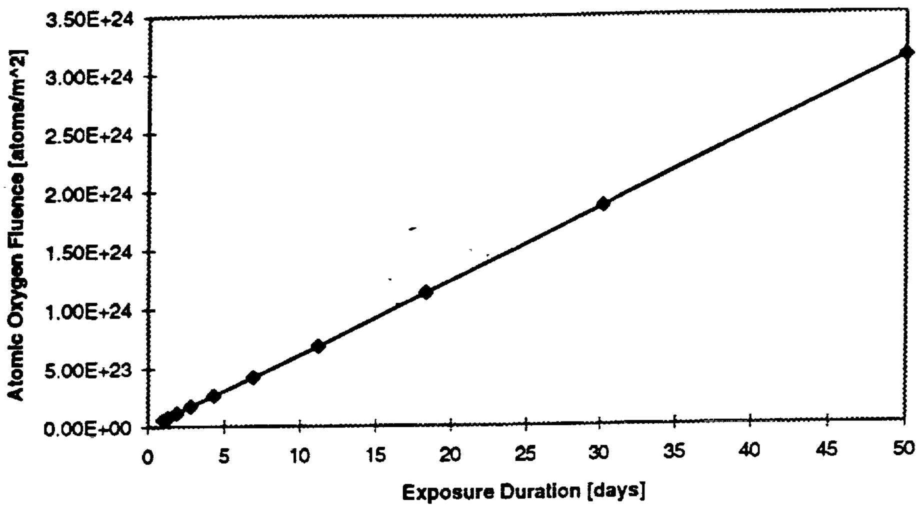

Figure 3.2.1 MSIS-86 calculation of atomic oxygen exposure for a nominal SSTO space station re supply orbit.

4.0 Comments

This review of adverse environments is not a comprehensive definition. Characterizing many of these environments remains an active area of research, however little significant change in these definitions is forecast. What is apparent is that these environments are complex, and accurately simulating all aspects of them under test conditions is unrealistic and unnecessary. However, some description of these environments must be agreed upon by the affected community so that test methods and conditions can be defined and used to appropriately characterize the performance of candidate TPS materials under realistic adverse environmental conditions.

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